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IMPACT OF BUFFER DISTRIBUTION IN PRECISION MANUFACTURING PROCESSES THROUGH SIMULATION METHODS

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ABSTRACT

Manufacturing system has become easier than ever before due to modern technologies. Simulation is very important technique for studying the efficiency of production systems and optimizing the manufacturing processes which aids long term production efficiency. In this study, we are using Tecnomatix Plant simulation software to identify throughput, machine utilization and buffer occupancy for the precision manufacturing processes. Production line simulation has done for the discrete interval time i.e. Poisson distribution (λ) and Log-normal distribution (σ, μ). Investigation was conducted for CNC machines with various buffer occupancy and availability of machines by detailed time study and flow of process along the line. This paper compares the impact of buffer allocation and availability of machines on the throughput rate design experimentation.

KEYWORDS: Throughput, Machine Utilization, Buffer Distribution & Production Line

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Original Article

INTRODUCTION

Today's competitive world leads to digitalization in the manufacturing system. Simulation analysis for optimizing the production flow with the influence of machine, buffers etc. plays major part. Due to customer demands, and because of increased short period of manufacturing, customer satisfaction has become challenging factor,. . Non-value added activities leads to increase in manufacturing cost and hence simulation helps to eliminate such non value added activities in the entire manufacturing system. Effective techniques are used to resolve manufacturing barriers such as lean principle and tools (5S, TPM, FMS, and Kanban). Simulation can also help in identifying bottlenecks in the production lines, workers requirement to operate machines and carry of parts. Many manufacturing problems can easy visualize and analysis using simulation methods. Buffer allocation gives optimal results in the closed production line, which is less effective to bottleneck analysis. Simulation experiments estimate the allocation capacity [1, 2] required for the production. Intermediate buffers are helps to increase the throughput and utilization of machine. Placement of buffers can be done in parallel or series depending on the design of lines. Total buffer allocation and optimization can be done using algorithms with respect to cycle time. Optimization has been done for ensuring availability of machines in percentages, where machines are under maintenance to repair for certain duration. Effective algorithms will be used to identify the throughput [3] with respect to availability of machine in terms of percentage. Some authors determine the buffer allocation cost i.e. space worth for each pair of work stations for different environment conditions. Conventional practice in manufacturing industries leads to un-necessary waste which is present in manufacturing line that can be removed by identifying the new process design and development of flow. Julia Siderska, investigated Computer simulations for different parameters where

repetition process is occurred for several times. Simulation aids that whole manufacturing process parameters with optimized and increased throughput [9]. Jingshan Li et al. studied the significant procedure to deal the unpredictable machines and intermediate buffer capacity to analysis of throughput in the automotive industry [8]. Design and operation management is a most strategic tool to deal real time data which helps in analysing the schedule of complex manufacturing systems. Islam F. Bourini et al. examines the' what if' simulation using Delmia Quest software by applying reliability for the production line to determine bottleneck, buffer size to minimize the production cost. JiaZhenyuan et al. used theoretical research to improve production efficiency and resource utilization [12] by eliminating waste and by applying neural networks. Madhu Sachidananda et al. explore the application of discrete simulation to improve throughput [11], better resource utilization and cost reduction. Arun Jayaraman et al. presented different scenario for the automobile industry such as with buffer [10] and without buffer, to save valuable time in the complex area. Yeong Wei Ng et al. presented shop floor performance with respect to volume of parts and various pattern flows for components [5]. He explored different models which maximizes the throughput rate and machine utilization. The failure of the machine [15] and equipments cause impact on the productivity, due to effect for other process in the production line. Simulation model describes the difficulty in real world manufacturing systems problem [14].

PROBLEM DESCRIPTION

Simulation is used to analyse the impact of machine availability and buffer capacity on the machine utilization and throughput rate. The issue is to identify suitable buffer size into buffer space in production line. Another problem is the machine breakdown that occurs during regular process intervals due to different reasons in the maintenance, which aids to time disperse. Hence availability of machine and capacity of buffer makes significant impact on throughput rate. Based on the objective function, it is classified as follows:

- To maximize machine utilization and throughput with the allocation of buffer capacity in the production line.
- To maximize machine occupancy and throughput by improving the machine availability percentage.
- To minimize capacity of buffer to attain necessary throughput and machine utilization.

In this, firstly we measured operation time and setup time (loading and unloading time of parts into the machine). To maximize the throughput rate and utilization of machine, proper buffer allocation should be done. At presence, the present production rate is not meeting the customer expectations and hence customer is unsatisfied. In our work, Tecnomatrix plant simulation software is supporting us in examining and validating results best buffer quantity with respect to throughput rate.

CASE STUDY

Simulation Model of Production Line

The model of the production line is dedicated to Multi-pin crank shaft precision manufacturing, where most of the machines are CNC used for micro finishing to the component. In this, production line has sixteen stages to complete the operations. Each stages of the production system frame a required number of resources. Production line simulation model was prepared with Tecnomatix PLM software 13.1 which is shown in figure 1. For production line simulation, it was assumed that the production line runs 6 days a week with three shifts per day. The total production time in the industry is 126 hours per week, same time that has used for simulation in this work.

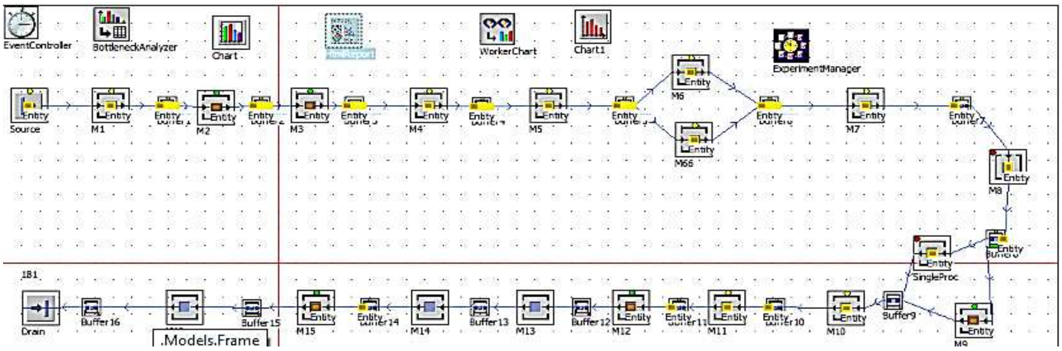

Figure 1: Simulation Model of Production Line.

In this simulation, neglecting the movement of operator's in the manufacturing plant during precision process and also we are not concentrating on how to improve the OEE (overall equipment efficiency) to maximize machine availability efficiency. The model was prepared based on the real manufacturing company. The operating time of each machine are based on Log-normal distribution (μ, σ) and interval based on passion distribution (λ). Log-normal distribution is calculated as follows:

$$f(x) = \frac{1}{\sigma_0 x\sqrt{2\pi}} \cdot \exp\left[\frac{-\ln(x-\mu_0)^2}{2\sigma_0^2}\right]$$

Where σ and μ are respectively mean and standard deviations and are defined as follows:

$$\mu = \exp\left[\mu_0 + \frac{\sigma_0}{2}\right]$$

$$\sigma^2 = \exp(2\mu_0 + \sigma_0^2)\cdot(\exp(\sigma_0^2) - 1)$$

The maximum of the density function is defined as:

$$\exp(\mu_0 - \sigma_0^2)$$

The Poisson distribution is calculated as follows:

$$f(k) = \frac{\lambda^k}{k!} \text{EXP}(-\lambda)$$

The availability of machines (%) is as shown in Table 1:

Table 1: Availability of Machines

Availability (%)	MTTR (min)
80	10
85	10
90	10

For simulation experiments, availability of machines is an important parameter with buffer allocations. The buffer size was selected based on the real manufacturing experience where exact requirement is gathered to improve throughput rate and machine utilization. The buffer size combinations were selected arbitrarily as shown in table 2:

Table 2: Allocation of Fixed Buffer Size

Experiment	Exp. 01	Exp. 02	Exp. 03	Exp. 04	Exp. 05	Exp. 06	Exp. 07	Exp.08	Exp.09
Buffer Size	5	8	11	14	17	20	23	26	29

The operation time of each machine for the production of component. Lower bound is the actual operation time upper bound has taken twice the lower bound and is shown in table 3:

Table 3: Operation and Setup Time of Machines

Machines	Interval time λ	Poisons distribution interval and Log-normal cycle time			
		Process time (mins)		Loading and unloading time (mins)	
		Lower bound	Upper bound	Lower bound	Upper bound
M1		8.57	17.14	0.20	0.40
M2		8.57	17.14	0.20	0.40
M3		4.50	9.00	0.10	0.20
M4		1.40	2.80	-	-
M5		1.50	3.00	0.15	0.30
M6		14.08	28.16	0.15	0.30
M7		13.04	26.08	0.15	0.30
M8		9.05	18.10	0.20	0.40
M9	5	35.08	70.16	0.20	0.40
M10		9.05	18.10	0.20	0.40
M11		2.00	4.00	0.10	0.20
M12		18.00	36.00	0.15	0.30
M13		3.00	6.00	0.10	0.20
M14		25.00	50.00	0.15	0.30
M15		7.50	15.00	0.10	0.20
M16		2.50	5.00	-	-

In this, we have selected fixed buffer size for all machines to identify the improvements with respect to each experiment. This buffer size was compared with the availability of machines to see the impact on machine occupancy and throughput rate (Table 4).

Table 4: Allocation of Random Buffer Size

Buffer	Exp 01	Exp 02	Exp 03	Exp 04
B_01	5	8	11	8
B_02	8	5	14	11
B_03	8	11	5	8
B_04	5	14	8	11
B_05	8	5	11	8
B_06	5	11	8	14
B_07	8	5	11	14
B_08	11	8	14	8
B_09	8	5	14	11
B_10	14	8	11	8
B_11	11	11	14	5
B_12	8	14	8	8
B_13	8	11	14	5
B_14	11	8	5	14
B_15	8	5	14	8
B_16	5	8	14	8

In this, buffer size allocation was selected arbitrary on the basis of simulation result obtained from the fixed quantity buffer size (Table 2).

RESULTS AND DISCUSSIONS OF SIMULATION

In this section, we analysed the results of simulation. Experiment showed the significant changes in the results for selected parameters of the production line. On the basis of production line model, simulation was performed for different experiment, operation time (Table 3) and availability of machine (Table 1). The results of throughput are shown in figures.

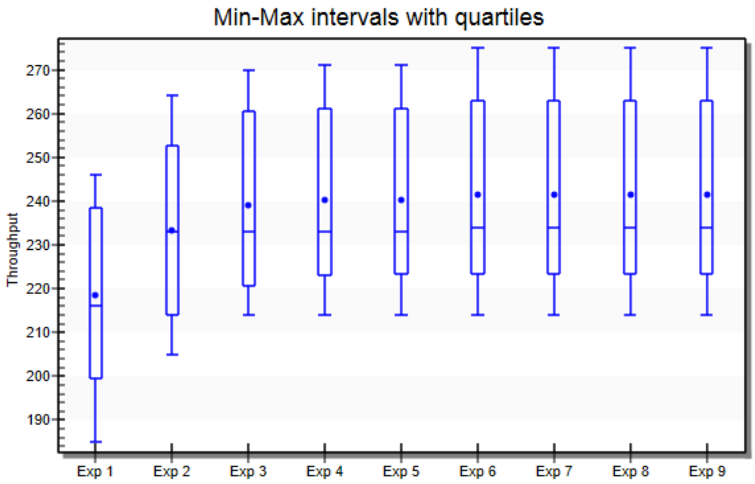

Figure 2: The Throughput Rate for 80% Availability of Machines.

The minimum average throughput obtained in Exp. 01 (219 components per week) for the buffer size five, whereas maximum throughput obtained in Exp. 03 (239 components per week) for the buffer size eleven. Further increase in the size of buffer will not impact on the throughput rate. As we used distribution bounds in operation time, we obtained the max-min intervals throughput (figure 2). In the Exp. 02, there was small increment in average throughput rate from 219 to 233 components per week. Interestingly, maximum throughput obtained for buffer size five is equal to the average throughput obtained in buffer size eleven. For eleven and above buffer size, there were little variations in maximum throughput (270-274 components).

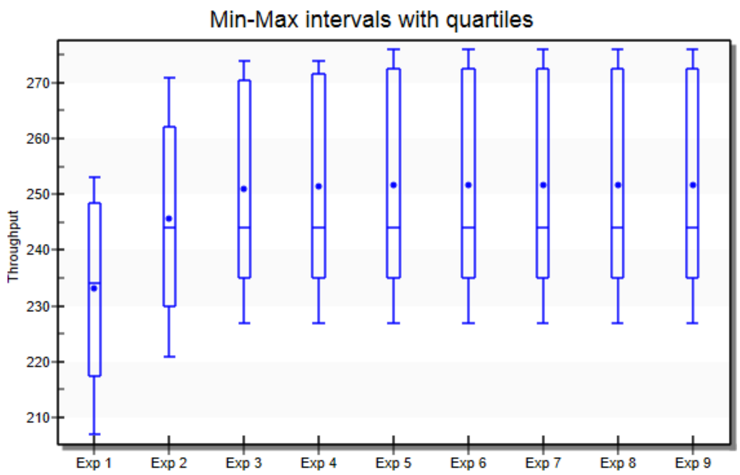

Figure 3: The Throughput Rate for 85% Availability of Machines.

The maximum average throughput was obtained in Exp.03 (250 components per week) for the buffer size eleven.

Here also, we obtained the same behaviour of throughput rate (figure 3), except, for the increase in the throughput rate as compared to 80 percentage availability of machines. As per the min-max intervals, we can obtain the maximum throughput about 276 components per week with the buffer capacity of eleven for the whole production line.

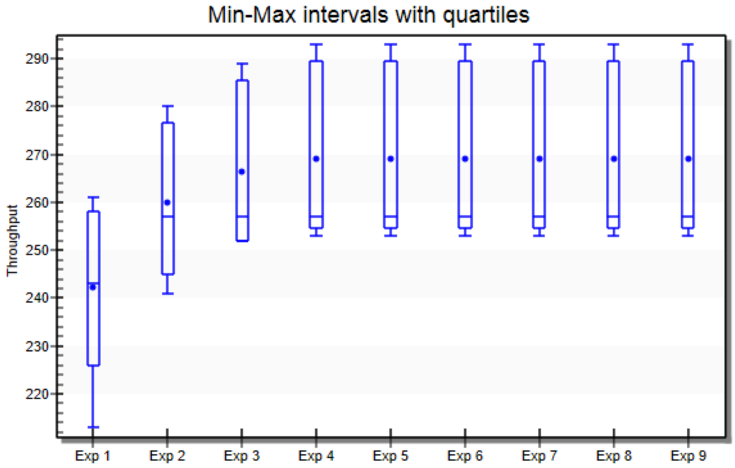

Figure 4: The Throughput Rate for 90% Availability of Machines.

The striking improvement of the throughput rate (figure 4) was seen as compared to 80 and 85 percentage machine availability. In this, we obtained minimum average throughput of 261 components for the buffer size five, which was not maximum throughput in the 80 percentage machine availability. For the eleven buffer size, we obtained average throughput of 266 components per week and maximum throughput was obtained in Exp. 04 (293 components per week) for the buffer size 14. The result of maximum throughput obtained in this machine efficiency varied from 11 to 14 buffer size.

The simulation results points out that average throughput time improves up to buffer size 11, , and throughput rate was constant beyond the buffer size from 14 to 29. The buffer allocations between machines was at maximum of 14. On the basis of above results, we have selected random buffer size between each machine as shown in Table 4. The random buffer size has simulated for different machines availability with constant MTTR (Table 1). These random buffer sizes impacts on throughput rate as follows.

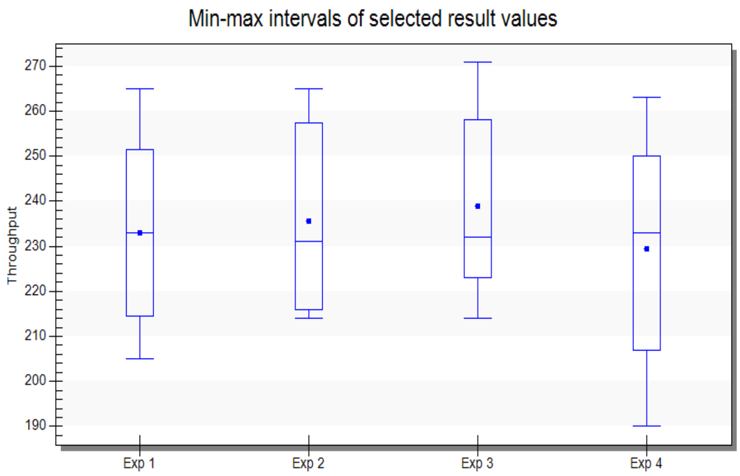

Figure 5: The Throughput Rate for 80% Availability of Machines for Random Buffer Size.

In this case, (figure 5) minimum values were obtained in Exp. 04 (230 components per week). Maximum average throughput value was obtained in Exp. 03 (240 components per week). Interestingly, we obtained variation of Max-Min interval throughput in Exp. 04. The maximum throughput rate was 270 components which is exactly equal to fixed buffer size throughput.

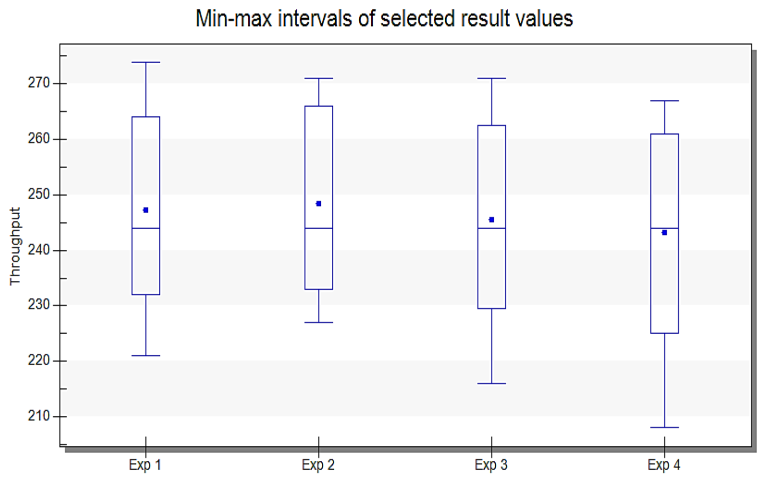

Figure 6: The Throughput Rate for 85% Availability of Machines for Random Buffer Size.

In this case, (figure 6) maximum average throughput rate was obtained in Exp. 02 (248 Components per week) and also maximum throughput value was obtained in Exp. 01 (274 Components per week), whereas same output was secured in Exp. 03 with 80 percentage machine availability. Here also, we obtained variation of max-min interval result in Exp 04.

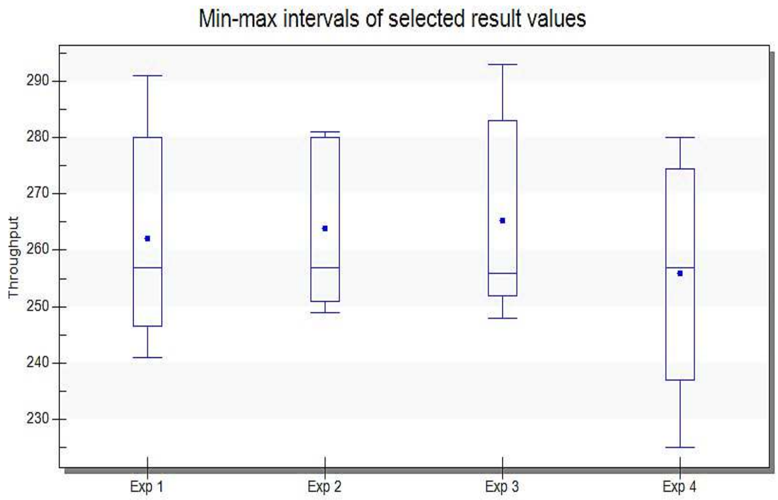

Figure 7: The Throughput Rate for 90% Availability of Machines for Random Buffer Size.

In this case, (figure 7) maximum average throughput was obtained in Exp. 03 (265 Components per week). Also, there was a very little variation between Exp. 02 and 03. In Exp. 02 max-min interval throughput rate was less as compare to all other scenarios. The max. Throughput of 290 components per week can be achieved.

In this section, the simulation result shows the lot of variation as compared to fixed buffer size with same

efficiency of machines. Allocation of suitable buffer between the machines leads to big impact on throughput and also identifying suitable buffer sizes aids in reduction of space in the manufacturing line.

The buffer size allocation and availability of machines also impact on the utilization of machines to improve productivity. The machine utilization for fixed buffer size was shown in figure 8 and 9.

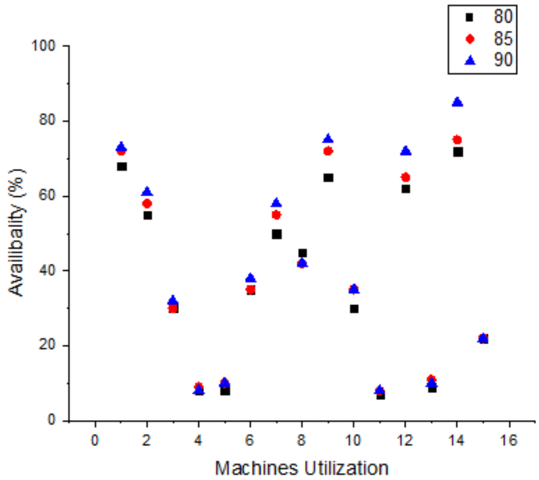

Figure 8: The Average Machine Utilization for the different Efficiency of Fixed Buffer Allocation.

In this section, the average utilization of machines (figure 8) for different efficiency was obtained. This result was based on the optimum buffer allocation during simulation. As we know the maximum buffer allocation in each machine was 11-14, the result shows based on these buffer sizes. Also machine occupancy depends on cycle time of the machines. As the efficiency difference was 5%, machine 1, 8 and 10 shows the very small variation in the occupancy during 80 and 85 percentage availability. The machine 3 and 6 shows the small variation in the occupancy during 85 and 90 percentage. The machine 4, 5, 11, 13 and 15 shows the small variations during 80, 85 and 90 percentage of machine availability. The machine 2, 7, 12 and 14 shows the major variations for all three different efficiency, due to distribution of operation time for mean and standard deviations, waiting time and blocking time.

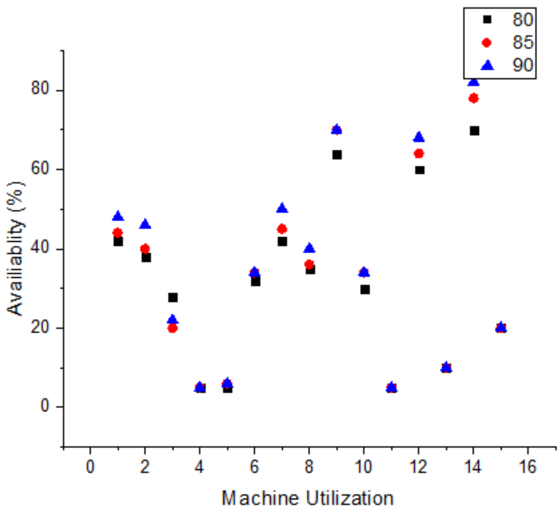

Figure 9: The Average Machine Utilization for the different Efficiency of Random Buffer Allocation.

The random buffer size allocation shows quit different statistics compare to the fixed number buffer size for the same production line (figure 9). In the machine 1, the utilization had small variation with 80 and 85 percentage, whereas in fixed buffer size allocation, it was around 85 and 90 percentages. The machine 4, 5, 11, 13 and 15 shows the similar behaviour during process. Major variations are observed in machines 8, 9 and 13 since the size of buffer allocated to respective machines are suitable to their respective efficienciess. The calculated actual buffer size varies from 5 to 14 for the cycle time which is enough to get maximum throughput time. In spite of the small variations, availability of machine is not shown in major variations.

CONCLUSIONS AND FUTURE WORK

Simulation Experiments results help us to identify suitable buffer size for the production line to different machine availability percentages. The machine utilization also varied for different size of buffer allocation with respect to cycle time. As we increase the size of the buffer, best throughput rate was achieved. Since, operation time of some of the machines is less than preceding and subsequent machines, the machine occupancy time does not have much variation. In the fixed buffer size allocation (5,8,11,14,17,20,23,26,29) maximum throughput value achieved in Exp. 03 (buffer size 11) as further increases in the buffer size and constant was maintained.

In both fixed and random buffer size allocation for different machine efficiency, throughput rate max-min value was almost equal, this shows that minimum buffer size of 5 is required where the machine has higher operating time and maximum buffer size of 11 is required for lower machine operating time. In the other case, as we selected random buffer size (5-14) for individual machine for machine availability, almost same throughput rate was obtained. For the production system, which was performed in this study, the following general conclusions can be formulated:

- The allocated buffer size has a considerable impact on the throughput and machine occupancy of the system.
- The suitable allocation of buffer sizes imparts superior values of throughput or machine utilization of the system.
- It is possible to improve the machine utilization by allocating the accurate buffer size between machines.

Further research will cover different models of the production system and the impact of operators on the throughput rate of the manufacturing system.

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